EFFECT OF DEFECTS ON THE MECHANICAL PROPERTIES OF COMPOSITE

A REPORT SUBMITTED IN PARTIAL FULLFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

By

Preetam Kumar Naik (107MM011)
Vinod Kumar Maliya(107MM010)

Under the Guidance of

Prof. B.B.Verma

Department of Metallurgical and Materials Engineering

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CERTIFICATE

This is to certify that the thesis entitled "**Effect of defects on the mechanical properties of composite"** submitted by **Mr. Preetam Kumar Naik** and **Mr. Vinod Kumar Maliya** in partial fulfillment of the requirements for the degree of Bachelor of Technology in Metallurgy and Materials Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted elsewhere for the award of any degree.

Date:

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ABSTRACT

This paper presents the study of effect of different types of defects on flexural strength of composite. Circular drillings of two different diameter extending upto neutral axis from the compression face and through holes at three different positions were made on specimens of different sizes to imitate defects during fastening by bolts. Epoxy filled half through holes have been tested to determine the extent of strength recovery and to check its feasibility in repairing damaged composites. The influence of delamination defect with change in number and location of delaminaton was analysed. The interlaminar fracture behavior of glass/epoxy composite has been preliminarily studied under flexural loading by using end-notched flexure (ENF) specimens. Two values of mode II strain energy release rate i.e G_{IIc} *were calculated, initiation value from the first non linear point on the load displacement graph and maximum value using the maximum force point and related displacement.*

CONTENTS

Introduction:-

1.1 Composite

Technological development depends on the advancement in understanding and application of materials. Design of an advance aerospace engine or superconducting device is of no use if required materials to bear the service load and environment are not available. Whatever the field may be, the final limitation on advancement depends on material development. Composite materials in this regard represent a giant leap that mankind has made towards optimization of materials.

The word "Composite" means "consisting of two or more distinct parts." Thus composite refers to two or more different constituent materials which are mechanically or metallurgic-ally bonded together separated by distinct interface.

Thus a material having two or more distinct constituent materials or phases may be considered a composite material. However, we recognize materials as composites only when the constituent phases have significantly different physical properties, and thus the composite properties are noticeably different from the constituent properties. For example metals almost always contain unwanted impurities or alloying elements; plastics generally contain small quantities of fillers and other materials used for commercial reasons such as economy and ease of processing, yet these generally are not called as composites. In the case of metals, the constituent phases often have nearly identical properties (e.g., modulus of elasticity), the phases are not generally fibrous in character, and one of the phases usually is present in small-volume fractions. Thus the modulus of elasticity of a steel alloy is insensitive to the amount of the carbide present, and metallurgists generally have not considered metal alloys as composites, particularly from the this point of view of analysis. Nevertheless, two-phase metal alloys are good examples of particulate composites in terms of structure. Although plastics— which are filled for cost purposes containing small amounts of additives— are composites, they need not be considered as such if their physical properties are not greatly affected by the additives. Thus classification of certain materials as composites often is based on cases where significant property changes occur as a result of the combination of constituents, and these property changes generally will be most obvious when one of the phases is in platelet or fibrous form, when the volume fraction is greater than 10%, and when the property of one constituent is much greater (5 times) than the other. The constituents combine at a macroscopic level and are not soluble in each other. Each of the various constituents retains its identity in the composite and maintains its characteristic structure and properties with distinct interface between them.

Composites are made up of individual materials called as constituent materials. There are two general categories of constituent materials: matrix and reinforcement. The reinforcing phase material i.e. reinforcement may be in the form of fibers, particles and flakes. At least one portion of each type is required .Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or reinforcing material whereas the continuous phase

usually softer termed the matrix. The most notable exception to this rule is the class of materials known as rubber-modified polymers, consisting of a rigid polymer matrix filled with rubber particles. Properties of composites are strongly depends on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume-fraction sum of the properties of the constituents(rule of mixtures), or the constituents may interact in a synergistic way so as to provide new properties in the composite that can not be accounted by a simple volume-fraction sum of the properties of the constituents. Thus, in describing a composite material as a system, besides specifying the constituent materials and their properties, one needs to specify the geometry of the reinforcement and its orientation with reference to the system. The geometry of the reinforcement may be described by the shape, size, and size distribution. However, systems containing reinforcements with identical geometry may differ from each other in many ways; for example the reinforcement in the systems may differ in concentration, concentration distribution and orientation. Therefore, all the above cited factors are important in determining the properties of the composites, but seldom are all accounted for in the development of theoretical descriptions of composites. The shape of the discrete units of the discontinuous phase often may be approximated by spheres or cylinders. There are some natural materials example mica, clay minerals and some man-made materials such as glass flakes that can best be described by rectangular cross-sectioned prisms or platelets. The texture of the material is controlled by size and size distribution. Together with volume fraction, they also determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Concentration is generally measured in terms of volume or weight fraction. The contribution of a single constituent to the overall properties of the composite is determined by this parameter. The concentration generally is regarded as the single most important parameter which determines the composite properties. Also, it is an easily controllable manufacturing variable used to alter the properties of the composite. The concentration distribution is a measure of homogeneity or uniformity of the system. Homogeneity is an important characteristic that determines the extent to which a representative volume of material may differ in physical and mechanical properties from the average properties of the material. Non uniformity of the system should be avoided because it reduces those properties that are governed by the weakest link in the material. For example, failure in a non uniform material will initiate in an area of lowest strength, thus adversely affecting the overall strength of the material(weakest link theory). The orientation of the reinforcement affects the isotropy of the system. When the reinforcement is in the form of particles, with all their dimensions approximately equal i.e. equiaxed the composite behaves essentially as an isotropic material whose properties are independent of direction. When the dimensions of the reinforcement particles are unequal, the composite may behave as an isotropic material provided that the particles are randomly oriented, such as in the randomly oriented short fiber reinforced composites. In other cases the manufacturing process (e.g., molding of a short-fiber composite) may induce orientation in a preferred direction and hence induce some anisotropy. In continuous-fiber-reinforced composites, such as unidirectional or cross-ply composites, anisotropy may be desirable. Moreover, the primary advantage of the composites is the ability to control anisotropy by design and fabrication depending on need. The concentration distribution of the particles refers to their spatial relations to each other. Particles may by

uniformly dispersed in a composite and placed at regular spacings so that no two particles touch each other. On the other hand, it is also possible to imagine a dispersion of particles so arranged that they form a network such that a continuous path connects all particles. This occurs at a much lower concentration than that at which the close packing of particles becomes possible. Such network-forming dispersions may have a significant effect on the electrical properties of the composites. An interesting example of this is the dispersion of carbon black in rubber. Above a volume concentration of about 10%, the electrical conductivity of the mixture increases remarkably. This is attributed to the network formation of carbon-black particles.

1.2 CLASSIFICATION OF COMPOSITE MATERIALS [13]

Most composite materials developed so far have been fabricated to improve mechanical properties such as strength, stiffness, toughness, and high temperature performance. It is natural to study together the composites that have a common governing strengthening mechanism. The strengthening mechanism depends strongly on the geometry of the reinforcement. Therefore, it is quite convenient to classify composite materials on the basis of the geometry of the reinforcement. Figure 1-1 represents a commonly accepted classification scheme for composite materials. Similarly figure 1-2 represents one of the commonly used classification scheme.

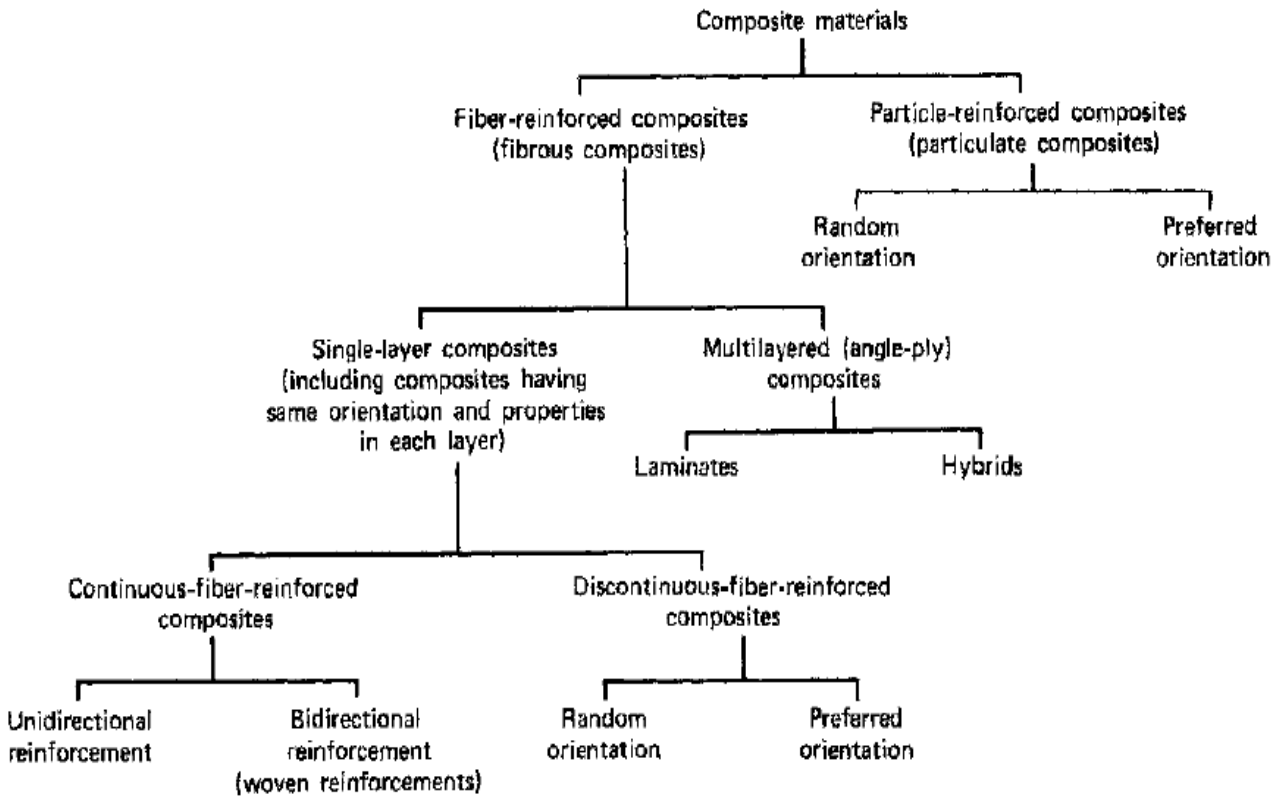


Figure 1-1. Classification of composite materials.

Figure 1

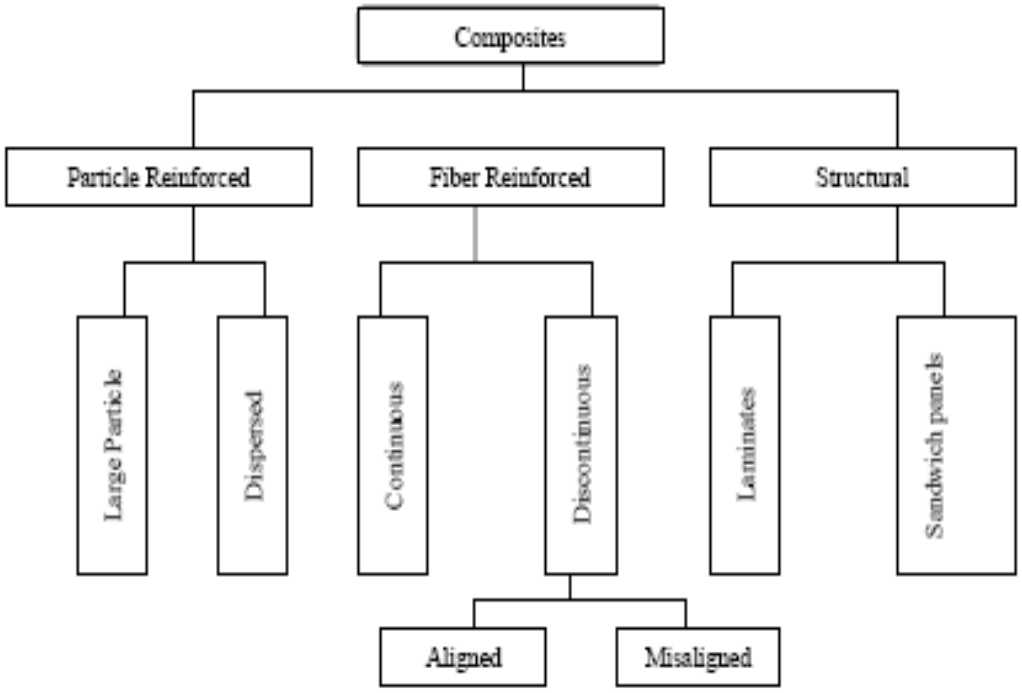


Fig. 1: Classification of composite types.

Figure 2

Composites classified by the geometry of the reinforcement – are particulate, flake and fibers.

Particulate composites comprises of particles immersed in matrices such as alloys and ceramics. They are usually isotropic since the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature and oxidation resistance etc. Typical examples are use of aluminum particles in rubber, silicon carbide particles in aluminum and gravel, sand & cement to make concrete.

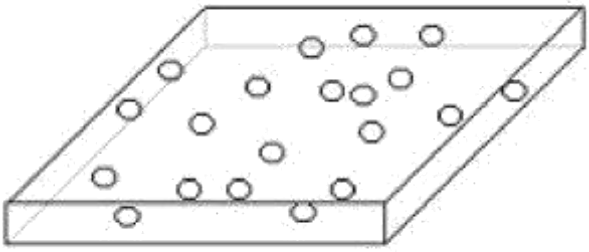


Figure 3 Particulate Composites

Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum and ceramics such as calcium-alumino silicate. The reinforcement of continuous fiber matrix composite are unidirectional or woven fiber laminas. Laminas are stacked on top of each other at various angles to form a multidirectional laminate.

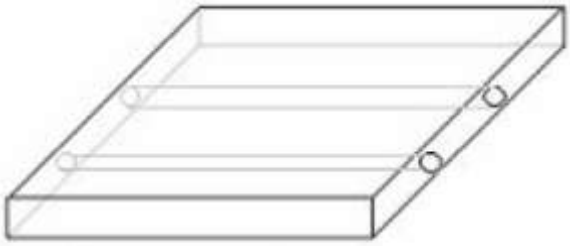


Figure 4 Fiber Composites

Flake composites consist of flat reinforcements of matrices. Typical flake materials are glass, mica, aluminum and silver. Flake composites provide advantages such as higher strength and low cost. However, flakes are difficult to orient and only a limited number of materials are available for use.

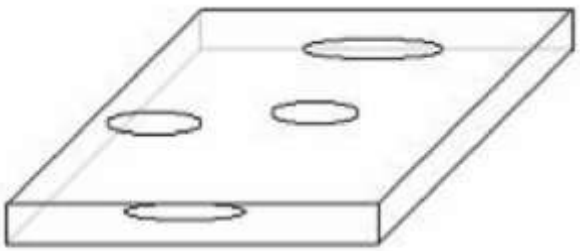


Figure 5 Flake Composites

Composite classified by the type of matrix – polymer, metal, ceramic and carbon.

Polymer Matrix Composites (PM Cs)

The most common and popular advanced composites are polymer matrix composites. These composites consist of a polymer (e.g. epoxy, polyester, etc) reinforced by thin-diameter fibers (e.g. glass, graphite, aramid). They have a high strength to weight ratio.For example graphite/epoxy composites are approximately five times stronger than steel on a weight- for-weight basis. The reasons for their popularity are low cost, high strength to weight ratio, simple manufacturing principles and ease of fabrication. The main drawbacks of PMCs include low operating temperatures depending on the polymer used as matrix, high coefficient of thermal, moisture expansion, and low elastic properties in certain directions. Applications of PMCs range from tennis racquets to the space shuttle.

Metal Matrix Composites (MMCs)

MMCs have a metal matrix. Examples of matrices in such composites include aluminum, magnesium and titanium. Typical fibers include carbon and silicon carbides. Metals are mainly reinforced to increase or decrease their properties to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased whereas large coefficients of thermal expansion and thermal and electrical conductivities of metals can be reduced by the addition of fibers such as silicon carbide.

MMCs are mainly used to provide advantages over monolithic metals such as steel and aluminum. MMCs have several advantages over PMCs, like, higher elastic properties, high service temperature, insensitivity to moisture, and better wear & fatigue resistance. However Reinforcing metals with fibers reduce ductility and fracture toughness. It is also costly and requires complex fabrication techniques compared to PMC's.

Ceramic Matrix Composites (CMCs)

CMCs have a ceramic matrix such as alumina, calcium alumino silicate reinforced by fibers such as carbon or silicon carbide. Advantages of CMCs are high strength, hardness, high service temperature limits for ceramics (1500 ° C), chemical inertness and low density. Reinforcing ceramics with fibers, such as silicon carbide or carbon, increases their fracture

toughness as it causes gradual failure of composite. CMCs are finding increased application in high temperature areas where MMCs and PMCs cannot be used. Typical applications include cutting tool inserts in oxidizing and high temperature environments specially in space applications.

Carbon-Carbon Composites (CCCs)

Carbon-Carbon Composites have carbon fiber in a carbon matrix. CCCs are used in very high temperature environments of up to 3315 ° C, and are 20 times stronger and 30% lighter than graphite fibers. Reinforcement of a carbon matrix allows the composite to fail gradually, and gives advantages such as ability to withstand high temperatures, low creep at high temperatures, low density, good tensile and compressive strengths, high fatigue resistance and high thermal conductivity. The main uses of CCCs are Space shuttle nose cones; Aircraft and formula one brake and mechanical fasteners required for high temperature applications.

1.3MECHANICAL ADVANTAGE OF COMPOSITE MATERIALS[12]

Two parameters are usually used to measure the relative mechanical advantage of composite materials. One parameter called the specific modulus is defined as the ratio between the Young's modulus (E) and the density (ρ) of the material. The other parameter called the specific strength is defined as the ratio of the strength (σult) and the density of the material (ρ), i.e.

$$\text{Specific modulus} = \frac{E}{\rho}$$

$$\text{Specific strength} = \frac{\sigma ult}{\rho}$$

The two ratios are high in case of composite materials. For example, the strength of a graphite/epoxy unidirectional composite is same as that of steel, but the specific strength is three times that of steel. What does this mean to a designer? Take the simple case of a rod designed to take a fixed axial load. The rod cross section of graphite/epoxy would be only one third that of steel. This reduction in cross-sectional area and mass translates to reduced space requirements, less material and energy costs.

Fibers such as graphite, aramid and glass have a specific modulus several times that of metals, such as steel and aluminum. This may give a false impression about the mechanical advantages of composites because they are made not only of fibers, but are combined with a matrix; and matrices generally have lower modulus and strength than fibers. Then question arises is the comparison of the specific modulus and specific strength parameters of unidirectional composites to metals now fair? The answer is no for two reasons. First, unidirectional composite structures are acceptable only for carrying simple loads such as uniaxial tension. In structures with complex requirements of loading and stiffness, composite structures including angle plies becomes necessary. Second, the strength and elastic moduli, of unidirectional composites, perpendicular to the fibers are far less.

1.4ADVANTAGES AND DISADVANTAGES OF COMPOSITES OVER METALS[13]

- Exhibit good dimensional stablity in space during temperature changes. Composites such as graphite/epoxy satisfy this requirement

.

- Good corrosion resistance.
- An important feature of some of composites is high strength to weight ratio. In aircrafts and automobiles use of composites saves the fuel by lowering the overall mass.
- Another outstanding feature, which makes composites advantageous over metals, is controlled anisotropy; this means the desired ratio of property values in different directions can be varied.
- Composite materials have improved strength, stiffness, and fatigue and impact resistance.
- Other advantages include ease of processing and structural forms that are otherwise inconvenient or impossible to manufacture.

.

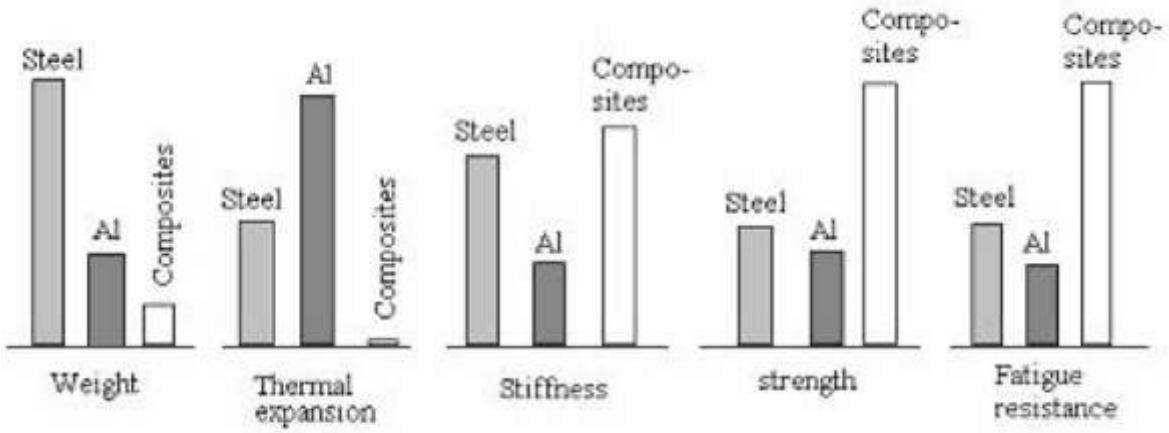
Table 1-1 Properties of fibers and conventional bulk materials

Material	Tensile Modulus (E) (GPa)	Tensile Strength (σ_u) (GPa)	Density (ρ) (g/cm^3)	Specific Modulus (E/ρ)	Specific Strength (σ_u/ρ)
Fibers					
E-glass	72.4	3.5[a]	2.54	28.5	1.38
S-glass	85.5	4.6[a]	2.48	34.5	1.85
Graphite (high modulus)	390.0	2.1	1.90	205.0	1.1
Graphite (high tensile strength)	240.0	2.5	1.90	126.0	1.3
Boron	385.0	2.8	2.63	146.0	1.1
Silica	72.4	5.8	2.19	33.0	2.65
Tungsten	414.0	4.2	19.30	21.0	0.22
Beryllium	240.0	1.3	1.83	131.0	0.71
Kevlar 49 (aramid polymer)	130.0	2.8	1.50	87.0	1.87
Conventional materials					
Steel	210.0	0.34–2.1	7.8	26.9	0.043–0.27
Aluminum alloys	70.0	0.14–0.62	2.7	25.9	0.052–0.23
Glass	70.0	0.7–2.1	2.5	28.0	0.28–0.84
Tungsten	350.0	1.1–4.1	19.30	18.1	0.057–0.21
Beryllium	300.0	0.7	1.83	164.0	0.38

[a] Virgin strength values. Actual strength values prior to incorporation into composite are approximately 2.1 (GPa).

Table 1

Figure 3 shows comparison of properties of fibers and conventional bulk materials



Comparison between conventional monolithic materials and composite materials

Figure 6 shows comparison between conventional monolithic materials and composite materials.

1.5APPLICATION [13]

Many composite materials are stronger than steel, lighter than aluminum and stiffer than titanium. They offer low thermal conductivity, good heat resistance, good fatigue life, low corrosion rates and sufficient wear resistance. For these reasons, they have become well established in a number of major areas.

Aircraft: The advantage of weight reduction makes composites preferable to metal parts. This has led to the increase in the use of composites in aircraft industry. Composites are used for making rudders, elevators, landing gear doors, panels, floorings and helicopter rotor blades.

Bridge repair Most bridges are built of steel-reinforced concrete because of its strength and durability; but after decades of supporting heavy loads, many bridges need to be repaired or replaced. A promising alternative to the enormously costly option of complete replacement is the use of graphite epoxy, a strong and lightweight carbon-reinforced polymer capable of withstanding heavy loads with very little maintainance.

Space: Two factors, high specific modulus and strength, and dimensional stability during large changes in temperature in space make composites the material of choice in space applications. Examples- payload bay doors in space shuttle and space shuttles' remote manipulator arm, which deploys and retrieve payloads, are made from graphite/ epoxy composites.

Sporting goods: Graphite/epoxy is replacing metals in golf club shafts, tennis racquets, ice hockey sticks, ski poles and bicycles mostly to decrease the weight. Composites also allow frames to consist of one piece that improves fatigue life, avoids the stress concentration found in metallic frames at their joints**.**

Medical devices: Applications here comprise glass/epoxy lightweight facemasks for epileptic patients, artificial portable lungs made of graphite- glass/epoxy so that a patient can be mobile and X-ray tables made of graphite/epoxy.

Automotive: Automotive applications of polymer matrix composites include fiberglass body and glass/epoxy composite leaf springs. Composite leaf springs have a fatigue life of more than five times that of steel and give a smoother ride than steel leaf springs. By weight, about 8% of today's automobile parts-including bumpers, body panels and doors-are made of composites to take advantage primarily of reduced weight. This results in reduced fuel usage and low cost of manufacture. Metal matrix composites are finding use now in automotive engines and gas turbine engines for their high strength and low weight than their

metal counterparts.

Military: In 2007, an all-composite military High Mobility Multi-purpose Wheeled Vehicle (HMMWV or Hummvee) was introduced by TPI Composites Inc and Armor Holdings Inc, the first all-composite military vehicle. By using composites the vehicle is lighter, allowing higher payloads. In 2008, carbon fiber and DuPont Kevlar (five times stronger than steel) were combined with enhanced thermoset resins to make military transit cases by ECS Composites creating 30-percent lighter cases with higher strength.

Commercial: Commercial applications are pressure vessels for chemical plants, garden tools and artificial limbs, which are lighter than traditional metal or wooden limbs, and hence are suitable for physically challenged people.

Other promising uses

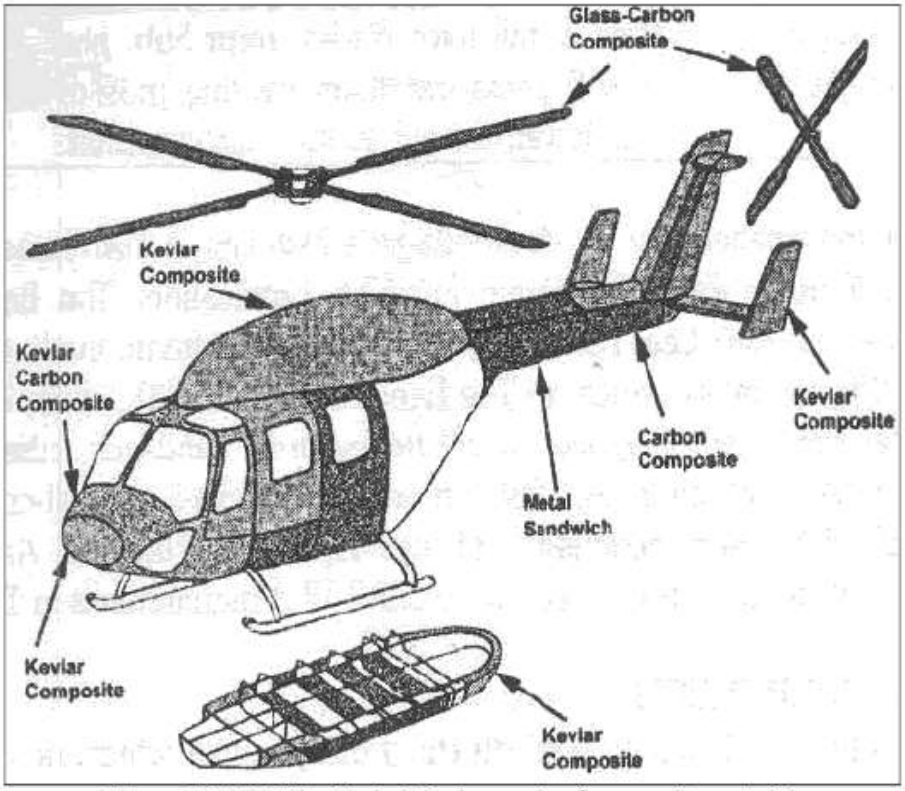


Figure M11.13 The Cockpit is also made of composite material

Figure 6

1.6Fiber-

A fiber is a slender, threadlike cylindrical structure whose length is much greater than its cross-sectional dimensions. Glass fibers are the oldest known fibers used to reinforce materials. Fibers, because of their small cross-sectional dimensions, are not directly usable in engineering applications. Therefore, they are embedded in matrix materials to form fiber reinforced composites. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage during handling.

Fibrous composites can be broadly classified as single- layer and multi- layer (angle-ply) composites. "Single layer" composites are made from several distinct layers with each layer having the same orientation and properties, and thus the entire laminate could be considered a "single- layer" composite. Most composites used in structural applications are multilayered; i.e. they consist of several layer of fibrous composites. Each layer or lamina is a single layer composite, and its orientation is varied according to design and requirement. When the constituent materials in each layer are the same, they are called laminates. Hybrid laminates refer to multilayered composites consisting of layers made up of dissimilar constituent materials.

Reinforcement(fiber) in a single- layer composite may be short or long compared to its overall dimensions. Composites with long fibers are called continuous-fiber-reinforced composites and those with short fibers, discontinuous- fiber-reinforced composites. A further distinction is that a discontinuous- fiber composite can be considered to be one in which the fiber length affects the properties of the composite. In continuous- fiber-reinforced composites it may be assumed that the load is directly applied to the fibers and that, the fibers in the direction of load are main load-carrying component. Thus, the principal purpose of a matrix is not to be a load-carrying constituent but essentially to bind the fibers together, transfer the load to fiber and protect them. The failure mode of such composites is also generally controlled by the fibers.

The continuous fibers in a "single- layer" composite may be aligned in one direction to form a unidirectional composite. Such composites are fabricated by laying the fibers parallel and saturating them with resinous material, such as polyester or epoxy resin, which holds the fibers in position and also serve as the matrix. Such forms of pre- impregnated fibers are called prepregs. The unidirectional composites are very strong in the fiber direction but are normally weaker in the direction perpendicular to the fibers. The continuous reinforcement in a single layer can be provided in a second direction to provide more balanced properties. The bidirectional reinforcement may be provided in a single layer in mutually perpendicular directions as in a woven fabric. The bidirectional reinforcement may be such that the strengths in two perpendicular directions are approximately equal.

The orientation of short or discontinuous fibers is not easy to control in a composite material. In most cases, the fibers are assumed randomly oriented in the composite. Different areas of a single molding can have quite different fiber orientations. Short fibers, occasionally referred to as chopped fibers, may be sprayed simultaneously with a liquid resin against a mold to build up a reinforced plastic structure. Alternatively, chopped fibers may be converted to a lightly bonded preform or mat that can be further impregnated with resin to fabricate single- layer composites. The chopped fibers usually lie parallel to the surface of the mold or are randomly oriented in planes parallel to the surface. Therefore, properties of a discontinuous- fiber-reinforced composite may be isotropic; i.e. their properties do not change with direction within the plane of the sheet. The two outstanding features of oriented fibrous composites are their high strength to weight ratio and controlled anisotropy. Controlled anisotropy means that the desired ratio of property values in different directions can be easily varied. For example, in a unidirectional composite, longitudinal strength to transverse strength ratio can be easily changed by changing the volume fraction of fibers.

1.7FIBER FACTORS AFFECTING PERFORMANCE OF A COMPOSITE [12]

Following fiber factors affects the mechanical performance of a composite:

Length: The fibers can be either long or short. Long continuous fibers are easy to orient and process, while short is difficult to control fully in preferred orientation. Long fibers provide many benefits over short fibers. These include enhanced impact resistance, low shrinkage, improved surface finish and dimensional stability. However, short fibers have few flaws and thereby have higher strength.

Orientation: Fibers oriented in one direction give very high stiffness and strength along that direction. If the fibers are oriented in more than one direction, such as in a mat, there will be high stiffness and strength in the directions of the fiber orientations. However, for the same volume of fibers per unit volume of the composite, it cannot be equivalent with the stiffness and strength of the unidirectional composites.

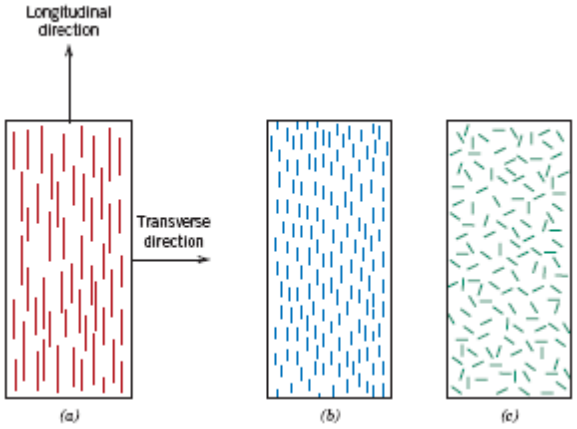


Figure 7

Schematic representations of (*a*)continuous and aligned, (*b*) discontinuous and aligned, and (*c*) discontinuous and randomly oriented fiber reinforced composites

Fiber Orientation	*Stress Direction*	*Reinforcement Efficiency*
All fibers parallel	Parallel to fibers	1
	Perpendicular to fibers	0
Fibers randomly and uniformly distributed within a specific plane	Any direction in the plane of the fibers	$\frac{3}{8}$
Fibers randomly and uniformly distributed within three dimensions in space	Any direction	$\frac{1}{5}$

Figure Reinforcement Efficiency of Fiber-Reinforced Composites for Several Fiber Orientations and at Various Directions of Stress Application **Source:** H. Krenchel, *Fibre Reinforcement,* Copenhagen: Akademisk Forlag, 1964

Shape: The most common shape of fibers is circular because handling and manufacturing them is easy. Hexagon and square shaped fibers are possible but their advantages of strength and high packing factors do not outweigh the complexity in handling and processing.

Material: The material of the fiber directly determines the mechanical performance of a composite. Fibers are generally likely to have high elastic modulus and strengths. This expectation and cost are the key factors in graphite, aramids and glass dominating the fiber market for composites.

Diameter: Fibers have a high aspect ratio (length to diameter ratio). The main reasons for using a thin diameter of fibers are the following:

1. Materials have actual strengths, which are several magnitudes lower than the theoretical strength. This difference is due to the inherent flaws in the material. Removing these flaws can increase the strength of the material. As the fibers become smaller in diameter, it reduces the probability of an inherent flaw in the material.
2. For superior ductility and toughness, and enhanced transfer of loads from the matrix to fiber,

composites require larger surface area of the fiber-matrix interface. For the same volume fraction of fibers in a composite, the area of the fiber- matrix interface is inversely proportional to the diameter of the fiber and can be proved as follows. Assuming a lamina consisting of 'N' fibers of diameter 'D'. The fiber-matrix- interface area A is

$$A = N\pi DL$$

Replacing the fibers of diameter 'D' by fibers of diameter 'd', then the number of fibers 'n' to keep the fiber volume the same would be

$$n=N(D/d)^2$$

Then, the fiber-matrix interface area would be

$$A = n\pi dL$$
$$= N\pi D^2 L\, d$$
$$= 4 \times (\text{Volume of fibers}) / d$$

This implies that for a fixed fiber volume in a given volume of composite the area of fiber-matrix interface is inversely proportional to the diameter of the fiber.

3. Fibers able to bend without breaking are required in manufacturing of composite materials, specially for woven fabric composites. Flexibility measured as the ability to bend increases with a decrease in the fiber diameter. Flexibility is defined as the inverse of bending stiffness and is proportional to the inverse of the product of the elastic modulus of the fiber and the fourth power of its diameter.

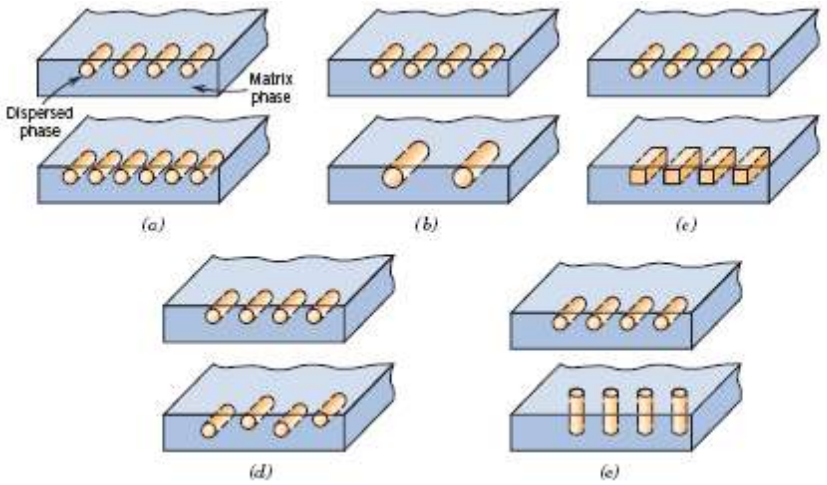


Figure 8

Schematic representations of the various geometrical and spatial characteristics of particles of the dispersed phase that may influence the properties of composites: (*a*) concentration, (*b*) size, (*c*) shape, (*d*) distribution, and (*e*) orientation. (From Richard A. Flinn and Paul K. Trojan, *Engineering Materials and Their Applications*,4th edition.)

Fiber	Advantages	Drawbacks
Glass (Most common fiber used in PMCs)	High strength, low cost, high chemical resistance, good insulating properties	Low elastic modulus, poor adhesion to polymers, sensitivity to abrasion, low fatigue strength
Graphite (Common in aircraft components)	High specific strength and modulus, low coefficient of thermal expansion, high fatigue strength	High cost, low impact resistance, high electrical conductivity
Metal	Easy production, high strengths, temperature resistance	Poor tolerance of high temperatures, high weight
Alumina (Aluminum oxide) fibers	Offers good compressive strength, high melting point (2000 °C)	Low tensile strength
Boron-tungsten fibers (Boron coated tungsten filament)	High stiffness, high strength	Low modulus of elasticity
Aramid	Low density, high tensile strength, low cost, high impact strength	Low compressive properties, degradation in sunlight

Table 2

In addition to the above- mentioned fibers, Silicon-carbide fibers and Quartz & Silica fibers are

also used as to reinforce composite materials.

1.8GLASS FIBERS[13]

Glass fibers are the most popular of all reinforcing fibers for polymer matrix composites. The use of glass fibres dates back to the ancient Egyptians For structural composites, the two commonly used types of glass fibers are E-glass and S-glass, because of their relative low cost and good quality. The E in E-glass stands for electrical as it was designed for electrical applications. The S in S-glass stands for higher content of silica. It retains its strength at high temperatures as compared to E- glass and has higher fatigue strength. It is used mainly for aerospace applications. The difference in the properties is due to the composition of E-glass and S-glass fibers. There are four main classes of glass used commercially-

high alkali (essentially soda-lime-silica: A glass), electrical grade (a calcium alumino-borosilicate with low alkali oxide content: E glass), chemically-resistant modified E glass grade (with calcium alumino-silicate: ECR glass) and high strength grade (with magnesium alumino-silicate and no boron oxide: S glass). Fibres from any of these can be prepared, however, E glass fibre is the one most widely-used for reinforcement purposes, although S glass fibre has the highest tensile strength and elastic modulus of these four types of glasses. C-glass (C stands for corrosion) used in chemical environments such as storage tanks and A- glass (A stands for appearance) used to improve surface finish. Combination types such as E-CR glass (E-CR stands for electrical and corrosion resistance), and AR- glass (AR stands for alkali resistance) also exist. The main disadvantage of glass fibers is their poor adhesion to polymer matrix resins, particularly in the presence of moisture. This poor adhesion requires the use of chemical (silane) coupling agents on the surface of fibers.

Table 2.3 Typical properties of different glass fibres

Material	Density (kg/m^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	CTE ($10^{-6}/K$)	Strain to Failure (%)
E-Glass	2620	3450	81	5.0	4.9
S-Glass	2500	4590	89	5.6	5.7
A-Glass	2500	3050	69	8.6	5.0

Table 3

Manufacturing: Glass fibers are made generally by drawing from a melt. The melt is formed in a refractory furnace at about 1400 °C from a mixture, which includes sand, limestone and alumina. The melt is stirred and maintained at a constant temperature. The melt passes through as many as 250 heated platinum alloy nozzles of about 10- µm diameter, where it is drawn into filaments of needed size at high speeds. These fibers are sprayed with an organic sizing solution before they are drawn. The sizing solution is a mixture of binders, lubricants, and coupling and antistatic agents; binders allow filaments to be packed in strands,

lubricants prevent abrasion of filaments, and coupling agents give better adhesion between the inorganic glass fiber and the organic matrix. Fibers are then drawn into strands and wound on a forming tube. Strands are groups of more than 204 filaments. The wound array of strands is then removed and dried in an oven to remove any water or sizing solutions.

Glass composition: Glass fibers are amorphous solids. Chemically, glass is composed primarily of a silica (SiO_2) backbone in front of ($–SiO_4–$) tetrahedra. Modifier ions are added for their contribution to glass properties and manufacturing capability.

Compositions of E-glass and S-glass fibers [9]

Material	(% Weight)	
	E-glass	S-glass
Silicon oxide	54.30	64.20
Aluminum oxide	15.20	24.80
Ferrous oxide	–	0.21
Calcium oxide	17.20	0.01
Magnesium oxide	4.70	10.27
Sodium oxide	0.60	0.27
Boron oxide	8.0	0.01
Barium oxide	–	0.20
Miscellaneous	–	0.03

Table 4

	E	S-2	H_R
Density			
lb/in^3	0.094	0.089	0.090
g/cm^3	2.59	2.46	2.49
Tensile Strength			
ksi	500	665	665
MPa	34,450	45,818	45,818
Modulus of Elasticity			
Msi	10.5	12.6	12.6
GPa	72.35	86.81	86.81
% Ult. Elongation	4.8	5.4	5.4
Dielectric Constant			
73°F (23°C) @ 1 MHZ	6.3-6.7	4.9-5.3	NA

Table 5

Table shows Typical glass fiber electrical and mechanical properties.

	E	S-2	S_R
Coeff. Thermal Expan. 10°			
in/in/F°	2.8	1.3	
m/m/C°	5.1	2.6	
Softening Point °F (°C)	1530 (832)	1810 (988)	1778 (970.)
Annealing Point °F (°C)	1210 (654)	1510 (821)	1490 (810.)

Table 6 shows typical glass fiber thermal properties

Fluid	E	S-2	S_R
10% H_2SO_4	42	6.8	NA
10% HCL	43	4.4	NA
10% HNO_3	43	3.8	NA
H_2O (Distilled)	0.7	0.7	NA
10% Na OH	29	66	NA
10% KOH	23	66	NA

Conditions: 200°F (96°C) - one week immersion

Figure shows Typical corrosion resistance of glass fibers (Wt. Loss %).

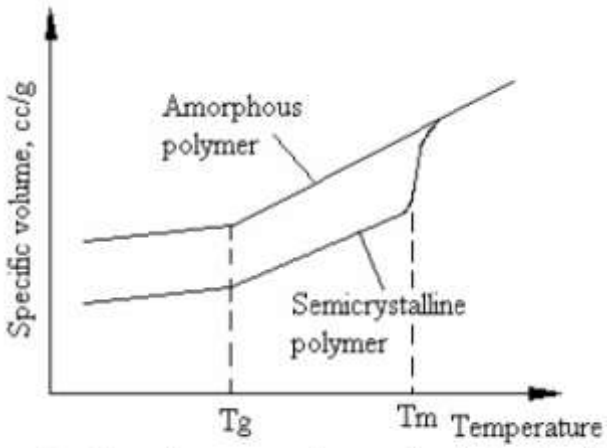
E Glass, Woven 7781 Style	Standard Structural	Dual Purpose Structural/Adhesive
Tensile Strength, ksi (MPa)	63 (430)	48 (330)
Tensile Modulus, Msi (GPa)	3.8 (36)	2.8 (19)
Compressive Strength, ksi (MPa)	60. (410)	50. (340)
Compressive Modulus, Msi (GPa)	3.6 (25)	3.2 (22)
Flexural Strength ksi, (MPa)	80. (550)	65 (450)
Flexural Modulus Msi, (GPa)	3.7 (26)	3.3 (23)
Interlaminar Shear ksi, (MPa)	2.6 (18)	3.8 (26)
Sandwich Peel, lb/in width (N/m width)	N.A.	30. (3.4)
Metal-to-Metal Peel, lb/lin. in. (N/lin. m)	N.A.	55 (6.3)
Specific Gravity gm/cm^3 (lb/in^3)	1.8 (0.065)	1.6 (0.058)
Cured Resin Content % Wt.	33	48

Table 7 shows typical cured epoxy/glass mechanical properties

1.9POLYMER MATRIX MATERIALS[13]

Polymers (commonly called plastics) are the most widely used matrix material for fiber composites. Their chief advantages are low cost, easy processibility, good chemical & resistance. On the other hand, low strength, low modulus, and low operating temperatures limit their use. Two main kinds of polymers are thermosetting polymers and thermoplastic polymers. The polymers that soften or melt on heating, called thermoplastic polymers, consist of linear or branched-chain molecules having strong intra molecular bonds but weak intermolecular bonds. Melting and solidification of these polymers are reversible and they can be reshaped by application of heat and pressure.

They are either semi crystalline or amorphous in structure. Examples include polyethylene, polystyrene, nylons, polycarbonate & polyamides. Thermosetting plastics have cross- linked or network structures with covalent bonds between all molecules. They do not soften but decompose on heating. Once solidified by a cross linking (curing) process, they cannot be reshaped. Common examples of thermosetting polymers include epoxy, polyesters, phenolics & melamine. The temperature limitations of a thermoplastic depend on whether it is semi crystalline or amorphous. Thermosetting plastics have amorphous structures, but thermoplastics may be either semi crystalline (they are never 100% crystalline) or amorphous. The amorphous state is characterized by a glass transition temperature (T_g) only, while the semi crystalline polymer has a crystalline melting point (T_m) as well as a glass transition temperature. These transition temperatures are shown in figure as measured by specific volume changes with temperature.



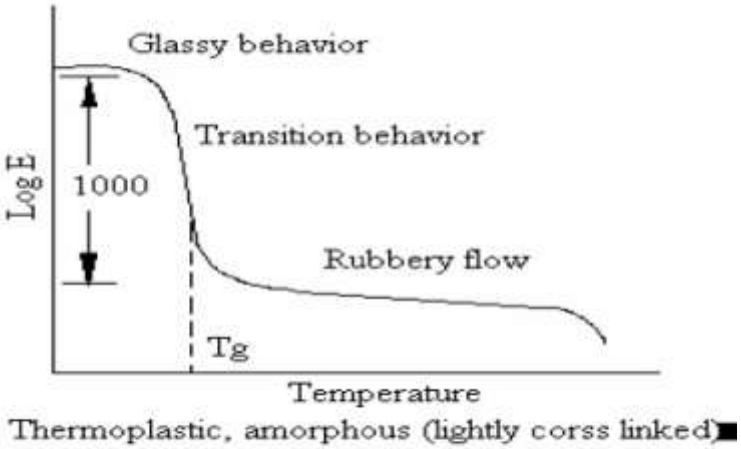
Specific volume versus temperature behavior of amorphous and semicrystalline polymers

Figure 9

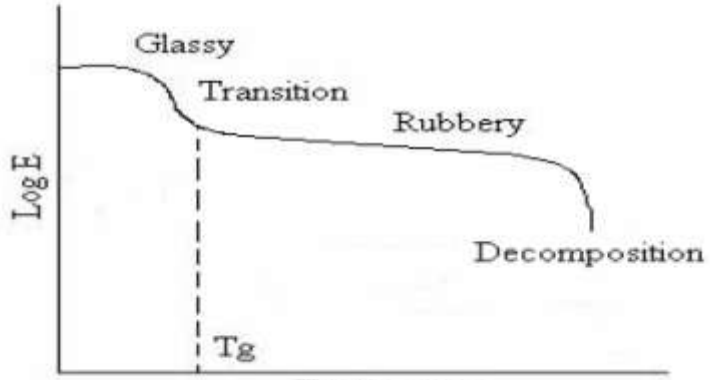
The temperature for processing of thermoplastics is governed by either the melt temperature or glass transition temperature. For example, an amorphous thermoplastic must be molded well above its T_g in order to sufficiently reduce its melt viscosity.

An understanding of the effect of these temperatures on the mechanical behavior of polymers is best seen by the behavior of modulus of elasticity (E) with temperature. An amorphous thermoplastic (e.g., polystyrene, polycarbonate) has a significant change of mechanical properties at the glass transition temperature. Hence, maximum use temperatures must be less than the glass transition temperatures. A thermoset (e.g., epoxy, polyester, phenolic) has a much-reduced change in properties at the glass transition temperature because of its high degree of cross- linking.

Figure 10



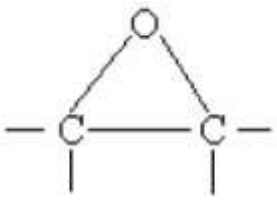
Thermoplastic, amorphous (lightly corss linked)



Thermoset, highly cross linked

1.10EPOXY RESINS [9]

Epoxy resins are low- molecular-weight organic liquids containing a number of epoxide groups, which are three- membered rings with one oxygen and two carbon atoms:



The most common process for producing epoxies is the reaction of epichlorohydrin with bisphenol-A amino or acid compounds, and cross- linking is obtained by introducing chemicals that react with the epoxy and hydroxy groups between the adjacent chains. The chemical reaction to form the epoxy resin prepolymer is as shown below:

— C — OH

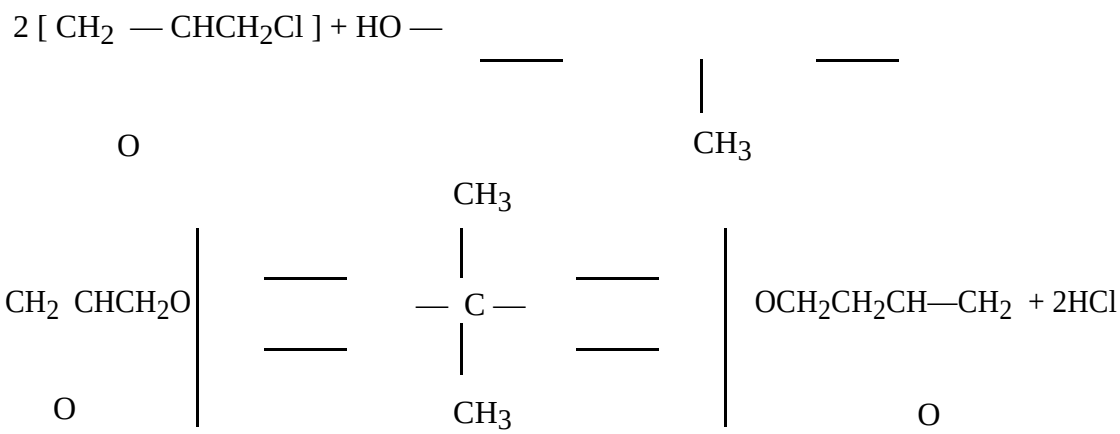


Figure 11

The epoxy resin is a viscous liquid, and the viscosity is a function of the degree of polymerization *n*. Each epoxy molecule is end-capped with the epoxy group. A curing agent is mixed into the liquid epoxy to polymerize the polymer and form a solid network crosslinked polymer. For example, diethylene triamine [used at 10 pph (parts per hundred)] achieves rapid cure at room temperature.

Diethylene triamine : $NH_2(CH_2)_2NH(CH_2)_2NH_2$

Five molecules of epoxy can react with each amine molecule through the active hydrogen on the nitrogen atom. A segment of fully cured structure is as follows:

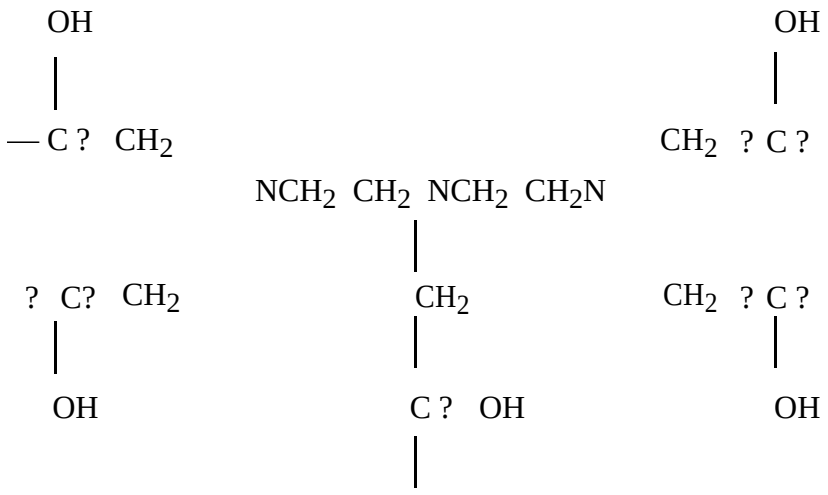


Figure 12

This reaction does not produce a by-product, but does produce heat accompanied with chemical shrinkage.

Epoxy systems, can be cured at room temperature, but quite often heat is added to accelerate and improve suring. The choice of cur ing agent dictates whether a room-temperature or elevated-temperature cure is required. The properties of a cured epoxy resin depend on the chemical composition of the epoxy prepolymer, which can be greatly modified, as well as the curing agent molecule.

Properties of cast epoxy resins (at 23 °C)

Density, g/cm3	1.2 – 1.3
Tensile strength, Mpa	55 - 130
Tensile modulus, Gpa	2.75 – 4.10
Water absorption, % in 24 h	0.08 – 0.15

Table 8

Epoxy systems are superior to polyesters particularly with regard to adhesion with a wide variety of fibers, moisture resistance and chemical resistance.

1.11FABRICATION OF THERMOSETTING MATRIX COMPOSITES [9]

Thermosetting resin systems, by chemical reaction become hard when cured, and further heating does not soften them – the hardening is irreversible. During curing they undergo a chemical change or reaction called polymerization, the linking of ”monomers or prepolymers” to form ” network polymers.” This reaction is accompalished in the presence of catalysts or curing agents usually selected to give a desired combination of time and temperature to complete the reaction suitable for a particular product.

Fabrication processes for thermosetting resin matrix composites can be broadly classified as wet forming processes abd processes using premixes or prepegs. In the wet forming processes, the final product is formed while the resin is quite fluid and the curing process is usually completed in one step.
Compounding (combining fibers and matrix) is done during forming. The wet processes include hand lay-up, filament winding, autoclave forming, pultrusion and resin transfer molding.

Hand Lay-up Technique

The hand lay-up technique is the simplest and the most commonly used method for the manufacture of both small and large reinforced products. A flat surface, a cavity (female) or a positive (male) – shaped mold, made from wood, metal, plastics, reinforced plastics, or a combination of these materials may be used. Fiber reinforcements and resin are placed manually against the mold surface. Thickness is controlled by the layers of materials placed against the mold. This technique, also called contact lay- up, is an open-mold method of molding thermosetting resins in association with fibers. A chemical reaction initiated in the resin by a catalytic agent causes hardening to a finished part.

The following operations are involved in a typical hand lay- up process:

Mold Preparation : This is one of the most improtant functions in the molding cycle. If it is done well, the molding will look good and separate from the mold easily. After the desired finish has been attained, several coats of paste wax are applied for the purpose of mold release.

Gel Coating : When good surface appearance is desired, the first step in the open- mold processes is the application of a specially formulated resin layer called the gel coat. It is applied first to the mold and thus becomes the outer surface of the laminate when complete. The gel coating may be painted on, or air-atomized with gravity or pressure feeding.

Hand Lay-up : After properly preparing the mold and gel coating it, the next step in the molding process is material prepartion. In hand lay-up, the fiberglass is applied in the form of chopped strand mat, cloth or woven roving. Premeasured resin and catalyst (hardener) are then throughly mixed together. The resin mixture can be applied to the glass either outside of or on the mold. To ensure complete air removal and wet-out, rollers are used to compact the material against the mold to remove any entrapped air. The resin-catalyst mixture can be deposited on the glass via a spray gun, which automatically meters and combines the ingredients.

Filament winding

Filament winding is a technique used for the manufacture of surfaces of revolution such as pipes, tubes and cylinders and is fequently used for the construction of large tanks and pipework for the chemical industry. Fibers are impreganted with a resin by drawing them through an in- line resin bath (wet winding) or prepegs (dry winding) are wound over a mandrel. Wet winding is inexpensive and lets one control the properties of the composites. Dry winding is cleaner but more expensive and hence quite uncommon. Depending on the desired properties of the product, winding patterns such as hoop, and helical can be developed. The product is then cured with or without heat and pressure. Mandrels are made of wood, aluminum, steel or plaster depending on the application.

Autoclave Forming

This method of manufacturing is used with composites available as prepegs. First a peel ply made out of nylon or cellophane coated with Teflon is placed on the mould. Tefolon is used for the easy removal of the part while the peel ply achieves a desired finish whihc is smooth and wrinkle free. Replacing Teflon by mold-releasing powders and liquids can also accomplish removal of the part. Prepegs of the required number are laid up one ply at a time either by automated means or by hand. Each ply is pressed to remove any entrapped air and wrinkles. The lay- up is sealed at the edges to form a vacuum seal. Now one establishes the bleeder system to get rid of the volatiles and excess resin during the heating and vacuum process which follows later. The bleeder system consists of several bleeder sheets made of glass cloth.

These are placed ont he edges and on the top of the lay-up. Then vacuum connections are placed over the bleeders and the lay-up is bagged. A partial vacuum is developed to smoothen the bag surface. The whole assembly is put in an autoclave where heat and pressure are applied with an inert gas such as nitrogen. The vacuum system is kept functioning to remove volatiles during the cure cycle and to keep the part conformed to the mold. The cure cycle may last more than 5 hr.

Pultrusion

Pultrusion is an automated process for manufacturing compsite materials into continuous, constant-cross-section profiles. This technique has some similarities to aluminum extrusion. In pultrusion, however, the product is pulled from the die rather forced out by pressure. A large number of profiles such as rods, tubes and various structural shapes can be produced using appropriate dies. The pultrusion process generally consists of pulling continuous rovings and/or continuous glass mats through a resin bath or impregnator and then into performing fixtures where the section is partially shaped and excess resin and/or air are removed. Then it goes into a heated die where the

section is cured continuously. The basic pultrusion machine consists of the following elements: (1) creels, (2) resin bath or impregnator, (3) heated dies, (4) puller or driving mechanism, and (5) cut-off saw. The pultrusion process is most suitable for thermosetting resins that cure without producing a condensation by-product (polyester and epoxy).

Resin Transfer Molding (RTM)

A low viscosity resin such as polyester or epoxy resin is injected under low pressure into a closed mold which contains the fiber preform. The resin flow is stopped and the part is allowed to cure. The cure is done either at room temperature or at elevated temperatures. The later is done if the part is to be used for high temperature application.

2.LITERATURE SURVEY

Recently a lot of research is going on to study the effect of defects on mechanical properties ofcomposite is going on. The defects may be present due to fault in fabrication or in some cases necessary as in case of joining by bolts,etc.

S.Y. Zhang, P.D. Soden and P.M. Soden [6] studied the inter laminar shear fracture of chopped strand mat glass fiber-reinforced polyester laminates both experimentally and analytically. Lap shear (double- grooved) specimens were used to measure the inter laminar shear strength and the cracking mechanism was studied using photomicrography.

Yob Saed Ismail ,Shukur Abu Hassan, Abd. Saman Abd. Kader ,Chong Chin Lee used end notched flexure (ENF) testing to determine the Mode-II interlaminar fracture toughness on various forms of E-glass fibre/thermoset based composites. The materials tested are unidirectional, woven roving and chopped strands mat with polyester and epoxy resins manufactured by hand lay up technique.

Okenwa I. Okoli, Ainullotfi Abdul- Latif [8] conducted a study to ascertain the relationship between the predicted and experimental data of the impact response of a reinforced composite laminate. The FEA was used to simulate impact behavior of glass fiber reinforced composites.

K. padmanabhan and Kishore studied the The flexural strength of the Kevlar/epoxy composite laminates, in the presenceof unfilled and filled circular defects. Circular drillings of two different diameters extending up to the neutral axis from the compression face as well as through holes, at three different positions from the midspan, have been considered as simplified cases of dents and defects. Bonded buttons of aluminium metal have been tested and shown to yield a strength-wise compensation for test samples with depressions.

A numerical and experimental study was carried out by Buket Okutan [5] to determine the failure of mechanically fastened fiber-reinforced laminated composite joints. E/glass–epoxy composites were manufactured to fabricate the specimens. Mechanical properties and strengths of the composite were obtained experimentally. A parametric study considering geometries was performed to identify the failure characteristics of the pin- loaded laminated composite. Data obtained from pin- loaded laminate tests were compared with the ones calculated from a finite element model.

Hossein Saidpour1, Mehdi Barikani2(*), and Mutlu Sezen3 studied Mode-II Interlaminar Fracture Toughness of Carbon/Epoxy Laminates under flexural loading by using end-notched flexure (ENF) specimens. GIIc values were calculated as total fracture toughness energy at the maximum load sustained by the materials as the delamination extended. The results showed that high temperature moulding systems (XHTM45) have the highest GIIc values well above 1000 J/ m2

Mir M. Atiqullah studied the effect of edge, central defect and central delamination over bending stress of a composite

3 SPECIMEN PREPARATION AND EXPERIMENTATION

3.1SPECIMEN PREPARATION

The selected specimen material was a fiberglass roving/epoxy (GFRP) composite, because of its widespread application in naval, automotive and aerospace industry. The composite was fabricated by Hand Lay-up method. The laminates are cured for 24 hrs. The composites fabricated are of 18 layers. The composite has a fiber weight fraction of approximately 60 %, epoxy matrix 40% and hardener (1/9) of the matrix.

The specimens prepared for the tests are:-

- Plain Glass fiber reinforced composite
- Glass fiber reinforced composite with
  - ❖ Through open holes ,holes of 2.5mm depth and epoxy filled holes of 2.5mm depth
  - ❖ Defects in form of laminates of Teflon of 12mm width is used at different location
  - ❖ End notched flexure specimen configuration for mode II testing

3.2RAW MATERIAL

The laminates were made from woven fiberglass (E-glass), consisting of 18 strands , epoxy as matrix and diamine as hardener.

Glass fiber

Figure 13

Glass fiber=60%

Epoxy =40% (2/3 of the wt. of fiber)

Hardener = (1/9) of the matrix

3.3HAND LAY-UP TECHNIQUE

Firstly, a layer of cellophane was placed on the drag to avoid the spoiling of the grinded surface and for the easy removal of the cured laminate. Pre measured resin and hardener for 18 laminates were thoroughly mixed together and applied on the fiberglass rovings using a brush. Defects were created by inserting a layer of Teflon of required length between the fiberglass rovings. To ensure complete air removal, rollers were used to compact the stack of fiberglass rovings against the mold to remove any entrapped air, but that, only after placing another layer of cellophane over the stack. Lastly, the cope was placed in the proper position and nuts were tightened to apply the pressure. The laminates were allowed to cure, at room temperature, for a period of 24 hours. Cured laminates were cut to dimensions by an watcr-cooled circular diamond cutter.

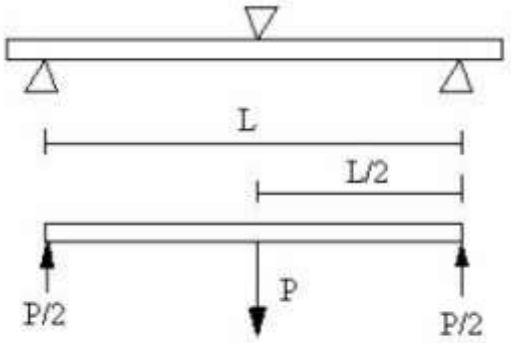
Fabricated specimen

Figure 14

4 EXPERIMENTATION

An experimental investigation was carried out to determine the flexural strength of the defected laminates subjected to bending. The laminates were tested in 3-point bending, on a Universal Testing Machine, INSTRON 1195 .

Figure 15



Three-point bending test

A beam subjected to bending moment and shear force undergoes certain deformations. The material of the member offers resistance or stresses against these deformations. A bending moment bends a member. The stresses introduced by bending moment are called bending stresses. In a beam, the bending moment is balanced by a distribution of bending stress. The top side is under compression while the bottom surface is under tension. The mid-plane contains the neutral layer which is neither stretched nor compressed and is subjected to zero bending stress. The line of intersection of the neutral layer with the cross-section of the beam is called as the neutral axis. According to Flexure formula:

$$\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$$

Where, M= Bending moment

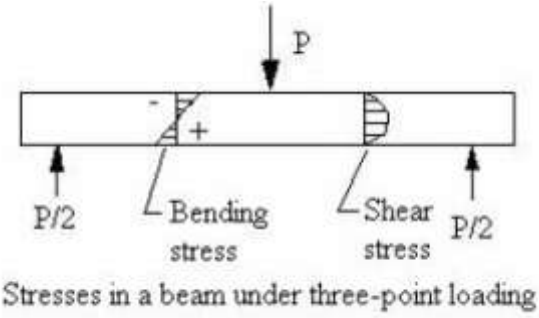
I = Moment of Inertia about neutral axis E=Young's Modulus of beam material R=Radius of curvature of neutral surface s =Bending stress

y=Distance of layer from neutral axis

Therefore, $\sigma = \frac{E}{R} y$

At neutral axis y = 0; s = 0

Figure 16



Stresses in a beam under three-point loading

The inter- laminar shear stress is maximum at the beam center. The stress state is highly dependent on the span-to-thickness ratio. Beams with small span-to-thickness ratio are dominated by shear. The short span, three-point bending test is commonly used for inter–laminar shear strength determination. Beams with long spans fail in tension or compression.

- **Defects in form of holes[12]**

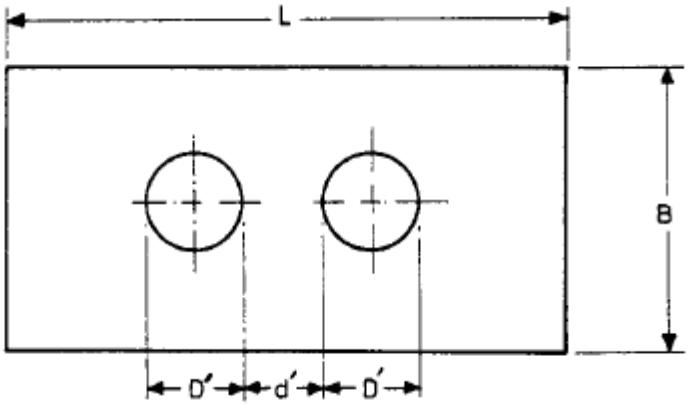


Figure 17 Representation of holes and depressions in a flexural sample.

D’ = 2 mm or 5 mm; d’ = .5 mm, 1 mm ,1.5 mm, 2 mm.

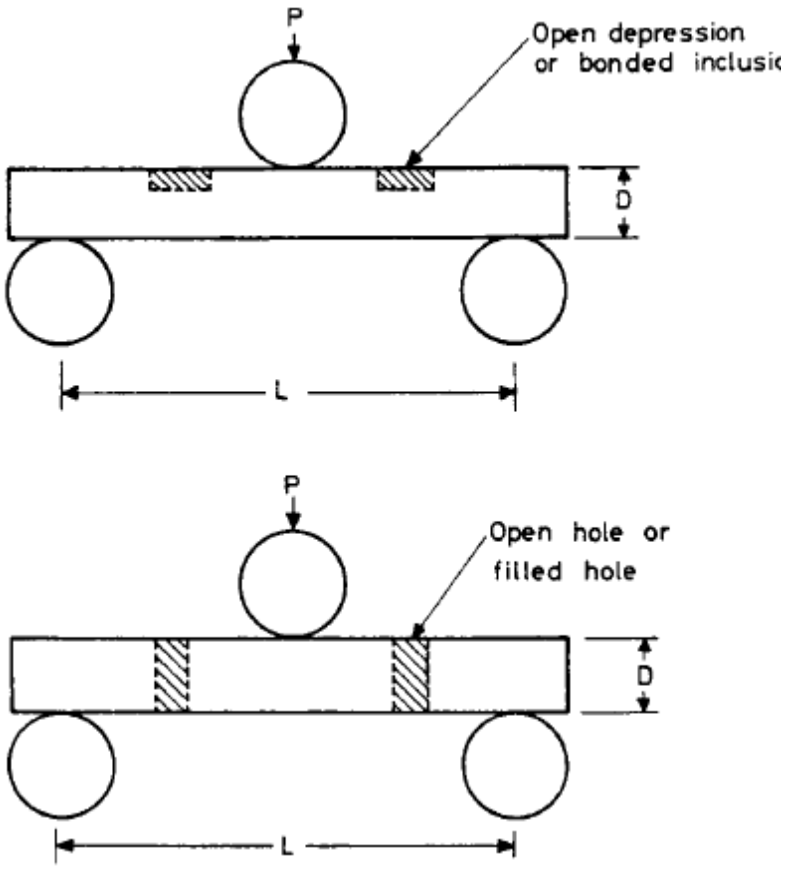


Figure 18 Flexural loading of specimens with depressions or holes (L = span length, D = thickness)

Flexural test of damaged and undamaged composite specimen is carried out.

- **Defects/delamination present at different location**:-

Defects in form of laminates of Teflon of 12mm width is used at different location. Flexural test is carried out to study the effect.

- **End Notched Flexure Mode II testing procedure**:-

The geometry of the end-notched flexure (ENF) specimens was the same as that for DCB test. The specimen was placed in a 3-point bend fixture with a half-span length L set to 50mm, as shown in Figure

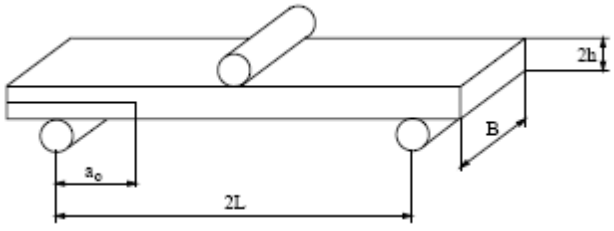
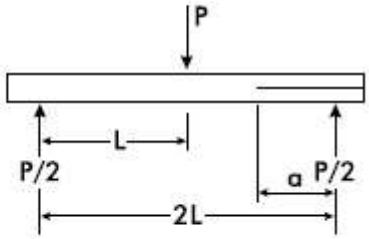
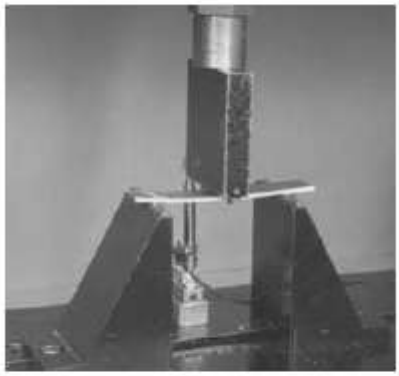


Figure 19



ENF specimen geometry



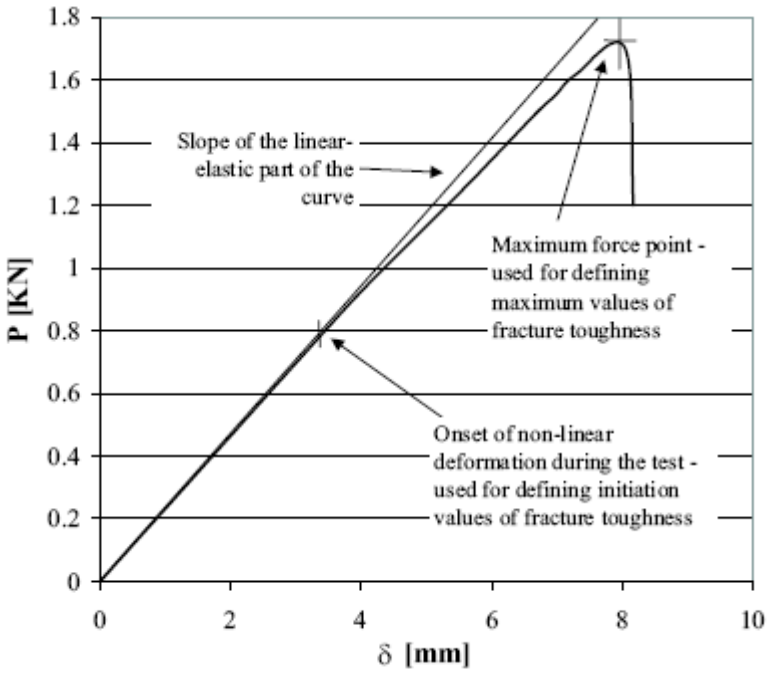
ENF test set up

Figure 20

The ENF specimen is 120 mm long and 10 mm wide. Specimen thicknesses for unidirectional carbon- and glass-fiber composites is 5 mm (60% fiber volume fraction), respectively. The specimen is loaded in a three-point bend fixture with a distance between thesupports, 2L, of 100 mm. Panels are prepared with a nonadhesive Teflon film of thickness less than 40μm placed at the midplane to define a starter crack. The thickness variations should not exceed 0.1 mm. The ENF specimen is placed in a standard three-point bend fixture so that a crack length, a, of 40 mm is achieved. Mark the support location on the specimen

edge for subsequent measurement of crack length. The center beam deflection (load-point displacement), δ is measured, with a linear variable differential transformer (LVDT), or from the crosshead displacement corrected for the machine compliance. A crosshead rate of 1 mm/min is used the load-displacement response is monitored.

Figure 21



Typical load-displacement plot under mode II loading - arrows mark the onset of the non-linear part of the curve and the point of maximum load, used for definition of the initiation and maximum fracture toughness values, respectively.

A load-displacement curve was obtained for the calculation of the mode II critical strain energy release rate, GIIc, based on the Direct Beam Theory where GIIc is expressed as

$$G_{IIc} = \frac{9a^2 P\delta}{2B(2L^3 + 3a^3)}$$

where L, a, and B are half-span length, starting defect length and width of the ENF specimen, respectively, while P and δ are the force and displacement recorded during the testing. Two values of GIIc were calculated, initiation values, using values of force and displacement from the first non-linear points on the force-displacement curves; and maximum values, using the maximum force point and the related displacement. These characteristic points are as depicted in Figure above.

5 RESULTS AND DISCUSSION

Composite laminates were tested in 3-point bending and a load verses displacement graph was plotted. The load was applied up to the point of fracture. The behavior of defected composites was obtained from the load/displacement graphs. Various defects such as longitudinal delamination, lateral multiple delamination between the fibers and at the two ends; depressions of 2.5mm depth(about half the thickness of the composite) ,through holes and epoxy filled holes were intentionally introduced in the composite specimen.

The flexural strength values reduced drastically in the open hole samples due to the crack on the tensile face of the samples near the hole edges (Figure 3). The fact that the failure due to bending of these samples initiated near the hole edges away from the midspan indicates stress redistribution due to the presence of holes [14]. This was true even in epoxy filled holes The results of various tests on through holes, holes of 2.5mm depth and epoxy filled holes are shown in following Tables in terms of strength reduction factor (SRF)] which is defined as[14]

$$\text{SEF or SRF} = \frac{\text{Notched strength with or without reinforcement}}{\text{Unnotched strength}}$$

Circular holes of 2mm dia in largespecimen

Specimen no.	Distance between the holes(d')	Span	Width	Depth	Flexural strength (MPa)	Strain at peak	SEF/SRF(Strength Reduction factor)
1. (WH)		50.0	10.0	5.0	344.0	.0188	1
2.(OH)	1	50.0	12.0	5.0	213.9	.0202	.62
3.(OH)	1.5	50.0	12.0	5.0	265.3	.0181	.77
4.(OH)	2	50.0	12.0	5.0	318.7	.0192	.92
5.(H)	1	50.0	12.0	5.0	237.7	.0182	.69
6.(H)	1.5	50.0	12.0	5.0	265.3	.0207	.77
7.(H)	2	50.0	12.0	5.0	323.1	.0195	.94

Table 9

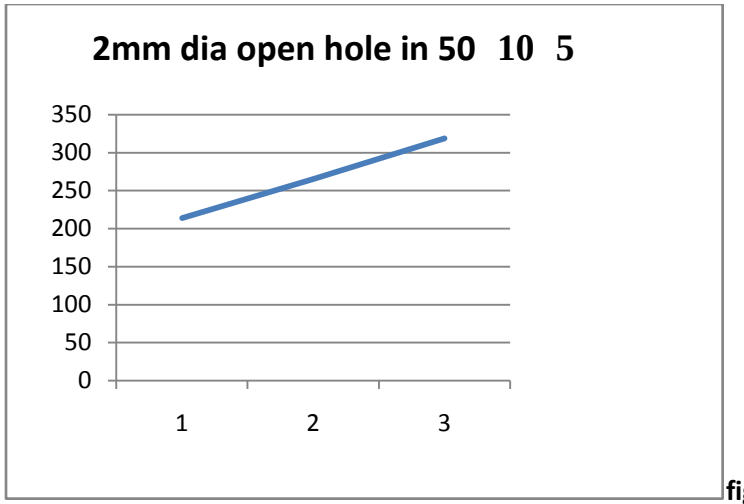


figure 22 shows plot of flexural strength versus d'

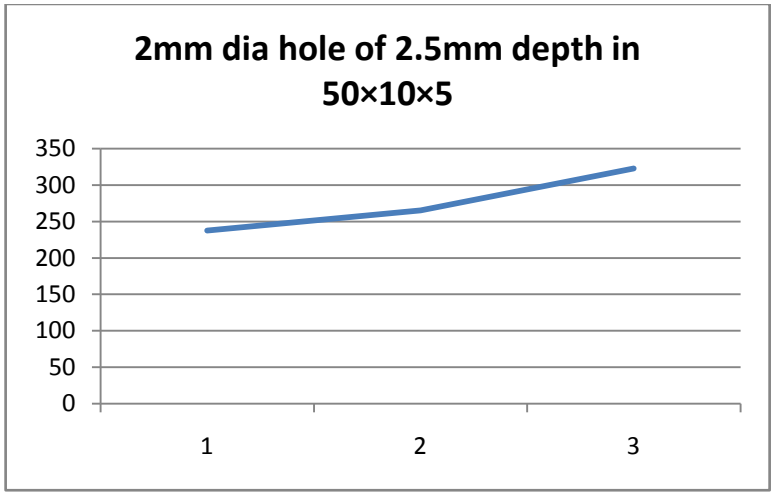


Figure 23 shows plot of flexural strength versus d'

Circular holes of 2mm dia in small specimens

Specimen no.		Span	Width	Depth	Flexural strength (MPa)	Strain at peak
1. (OH)	.5	40.0	6.0	5.0	238.9	.0241
2. (OH)	.5	40.0	7.0	5.0	232.3	.0198
3. (OH)	1	40.0	7.0	5.0	289.2	.0241
4. (OH)	1	40.0	6.0	5.0	303.2	.0299
5. (OH)	1.5	40.0	6.0	5.0	300.8	.0263
6. (OH)	1.5	40.0	7.0	5.0	254.8	.0187
7. (H)	.5	40.0	6.0	5.0	309.3	.0334
8. (H)	1	40.0	7.0	5.0	328.9	.0262
9. (H)	1.5	40.0	6.0	5.0	335.4	.0286

Table 10

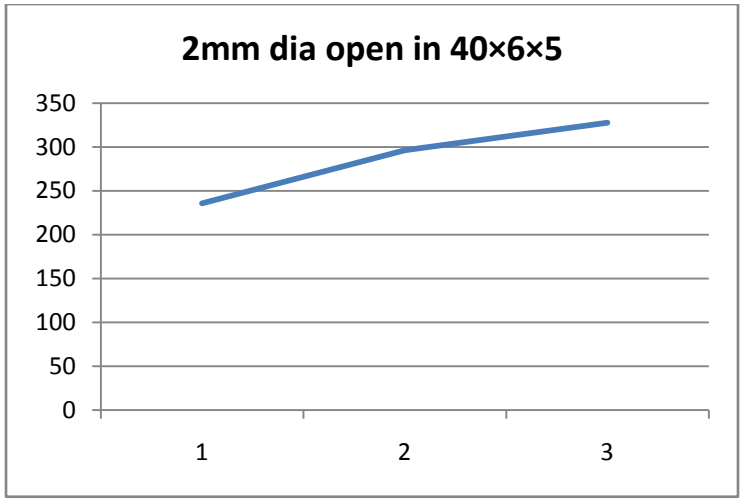


Figure 24 shows plot of flexural strength versus d'

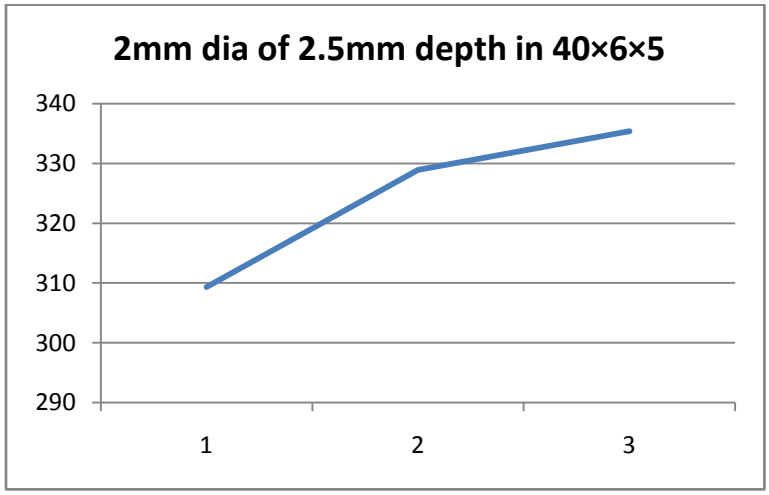


Figure 25 shows plot of flexural strength versus d'

Circular holes of 5mm dia								
Specimen no	Distance between the holes(d')	Span	Width	Depth	Flexural strength (MPa)	Strain at peak	Modulus (MPa)	SEF/SRF(Strength Reduction factor)
1. (WH)		50.0	10.0	5.0	344.0	.0188	22300	1
2. (FH)	1.0	50.0	12.0	5.0	275.4	.0235	16270	.80
3. (H)	1.0	50.0	11.0	5.0	247.0	.0174	16960	.72
4. (OH)	1.0	50.0	12.0	5.0	218.9	.0187	14690	.636
5. (FH)	1.5	50.0	12.0	5.0	281.6	.0173	19453	.82
6. (H)	1.5	50.0	12.0	5.0	271.6	.0211	16660	.79
7. (OH)	1.5	50.0	12.0	5.0	244.0	.0167	18010	.70
8. (FH)	2.0	50.0	11.0	5.0	318.2	.0177	20180	.925
9. (H)	2.0	50.0	12.0	5.0	286.0	.0186	17270	.83
10. (OH)	2.0	50.0	12.0	5.0	253.4	.0217	14990	.73

Table 11

Where H:- Holes of depth 2.5mm

FH:- Epoxy filled holes

WH:-without defects OH:- Open holes

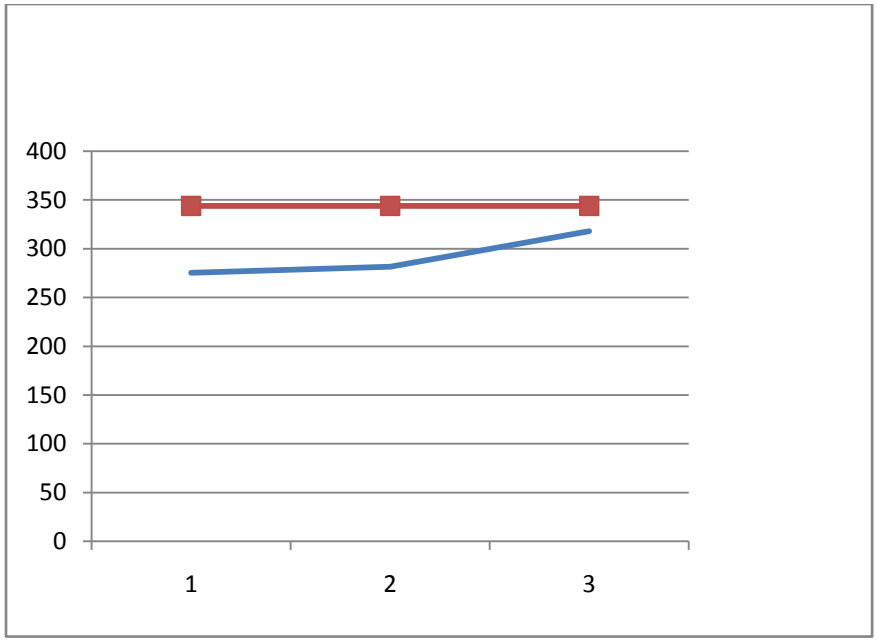


Figure 26 shows plot of flexural strength versus d' ,the straight line shows the flexural strength of composite without holes

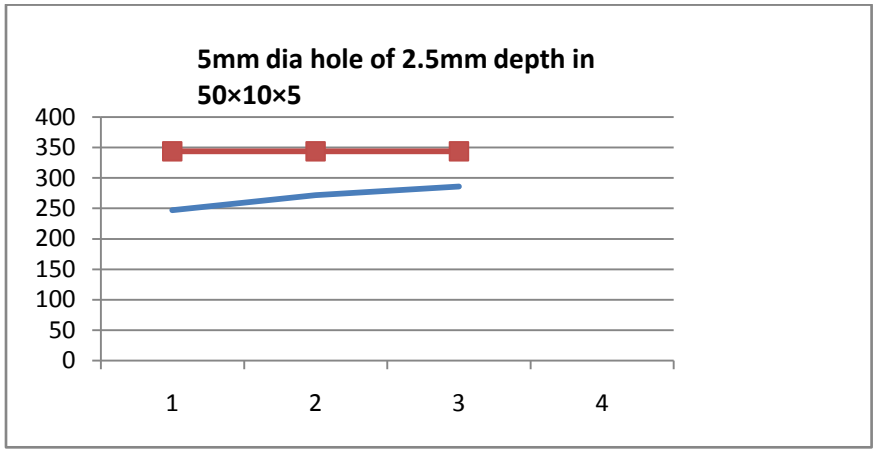


Figure 27 shows plot of flexural strength versus d' ,the straight line shows the flexural strength of composite without holes

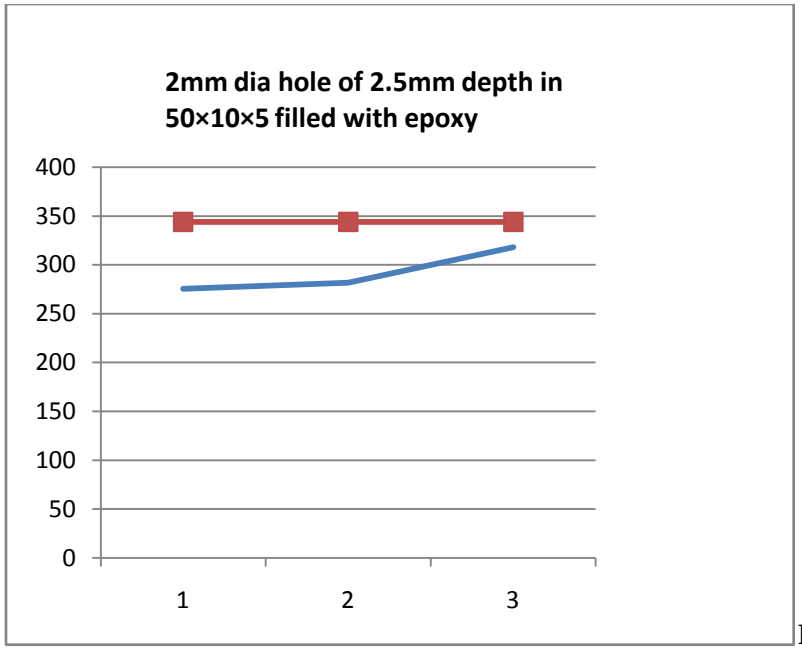


Figure 28 shows plot of flexural strength versus d' ,the straight line shows the flexural strength of composite without holes

It is clearly seen from the tables and graphs that the strength of the laminates with through holes is reduced significantly due to the stress concentration effects in the tensile face. However, the strength reduction was lower for epoxy filled holes and holes of 2.5 mm depth compared to open holes. It is to be noted that epoxy serves as an adequate filler material for an open depression (or pit). In general, the laminates with epoxy-filled depressions of 5 mm dia when holes are greater than 1mm exhibited little or no change in the strength values compared to plain without defect laminates. The above results clearly highlight the fact that a composite containing defects in the form of depressions or through holes, shows lower flexural strength values when compared to undamaged laminates. It also shows how this loss in strength can be retrieved to some amount by resorting to filling the depressions with epoxy resin.

Specimen – 1

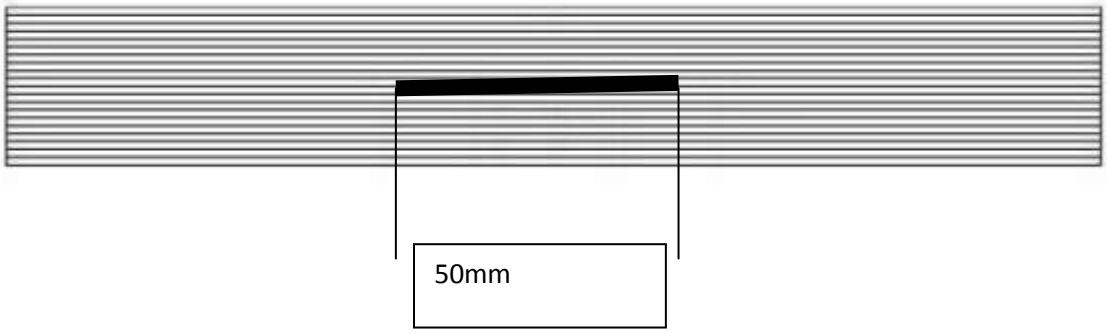
With no defects

Figure 29

Specimen – 2

With central defect/delamination

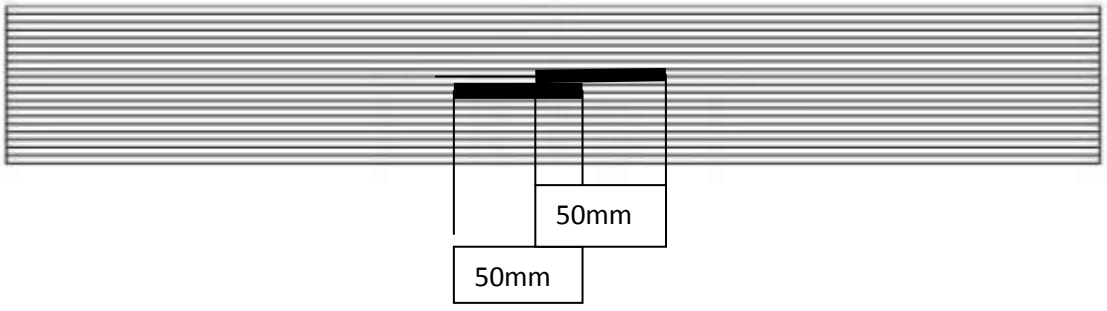
Figure 30



Specimen – 3

With multiple overlapping defect/delamination

figure 31



Specimen – 4

With side defects/delamination

Figure 33

Specimen – 5

With defect/delamination at both sides

Figure 34

Teflon insert of different sizes at different locations

Specimen no	Teflon location (50×12)mm	Span	Width	Depth	Flexural strength (MPa)	Strain at peak
1.	No defect	120.0	11.0	5.0	317.4	.0138
2.	central	120.0	10.6	7.0	155.0	.0143
3.	Multiple	120.0	9.6	6.4	132.4	.0183
4.	At one end	120.0	11.0	5.5	210.7	.0151
5.	At both ends	120.0	10.2	7.2	166.8	.0168

Table 12

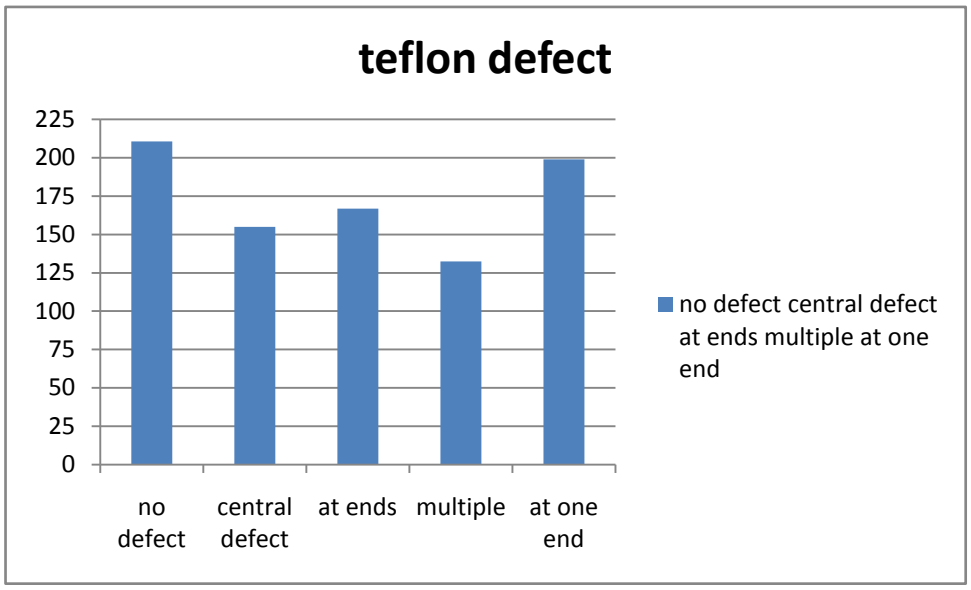


Figure 35 shows flexural strength of composites containing defects at different locations

The above graph shows that central delamination and multiple delamination result in large decrease in flexural strength than when delamination is present on the edges of the specimen.

Teflon insert ENF specimen

Specimen no	Span	Width	Depth	Flexural strength (MPa)	Strain at peak
1.	100.0	10.0	5.0	178.1	.221
2.	100.0	11.0	5.0	244.2	.0144
3.	100.0	11.0	5.0	174.2	.0240
4.	100.0	11.0	5.0	198.9	.0235
5.	120.0	11.0	5.0	317.4	.0138

Table 13

Unlike mode I DCB testing, mode II testing is still not fully standardized by the ASTM. The existing European protocol for composite delamination testing (ESIS) defines two different testing coupon geometries: End-Notched Flexure and End-Loaded Split (ENF and ELS) and three different procedures for specimen preparation. The JIS suggests mode I pre-cracking with the ENF specimen geometry. The ESIS protocol recommends testing of both pre-cracked (under tension or shear) and unprecracked specimens for a new material because there are still some uncertainties about which method will give the most relevant initiation values of GIIc]. For this study the DCB specimen preparation procedure was followed for mode II ENF specimens. Crack growth for all tested specimens was completely unstable

$$G_{IIc} = \frac{9a^2 P\delta}{2B(2L^3 + 3a^3)}$$

Teflon insert ENF specimen

Specimen no.	Starting defect length (a) in mm	Load at where non-linearity begins(P) in KN	Load at peak (P) in KN	Displacement at where non-linearity begins (δ) in mm	Displacement at peak (δ) in mm	G_{IIc} initiation In (J/m^2)	G_{IIc} maximum In (J/m^2)
1.	40	.16	.29	3	7	781	3306
2.	43	.28	.43	1.7	6	711	3820
3.	43	.2	.32	3	7.5	888	3554
4.	40	.23	.36	2	7.5	681	3998
Mean						765.25	3669.5

Table 14

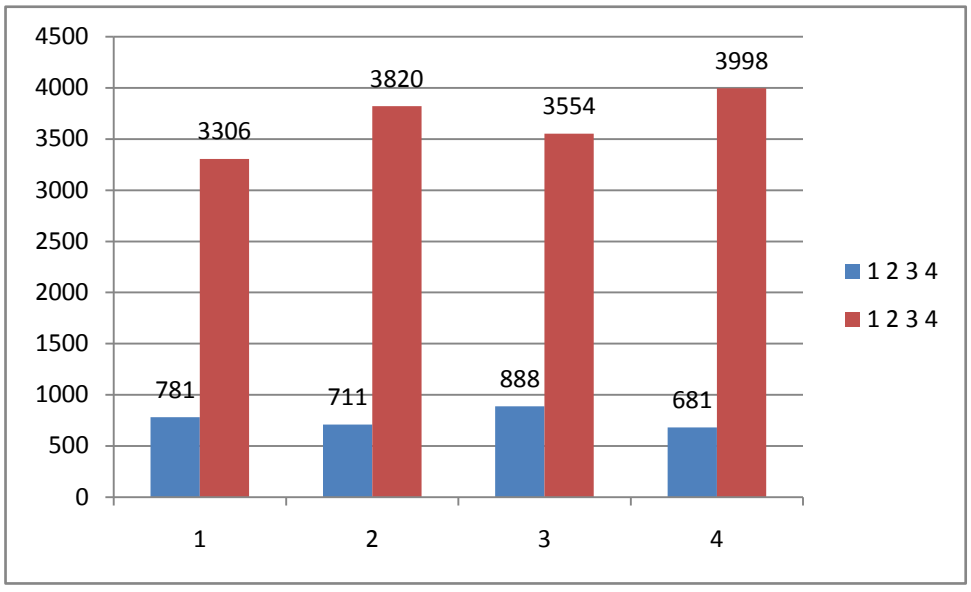


Figure 36

CONCLUSION

- Through holes reduced the flexural stress of glass/epoxy composites considerably. A crack is noticed on the tensile face of the specimen near the hole edges. However, the flexural strength reduction due to the half through holes of is higher compared to the through holes.
- The effect of holes diminishes with increase in distance between the holes increases. This is found valid for both the through and half through holes.
- Failure due to bending of most of the specimens initiated near the hole edges away from the mid-span. This may be due to holes induced stress redistribution.
- The flexural strength is retrieved effectively by filling the half through holes with epoxy.
- central delamination and multiple delamination result in large decrease in flexural strength than delamination on the edges of the specimen**..**
- ENF specimen is used to preliminary determine the Mode-II interlaminar fracture toughness of glass fibre reinforced composites. The value of obtained G_{IIc} need to be verified by conducting more rigorous experimentations.

Future Work:-

- Further investigation of mode II fracture toughness of glass fiber reinforced composite with more number of specimen to verify the value of obtained G_{IIc}.
- Aluminium disks can be bonded in depressions of 2.5 mm depth to ascertain its effect.
- The effect of filling depressions by epoxies on holes of different diameter needs to be verified.

REFERENCES

[1] Hossein Saidpour1, Mehdi Barikani2(*), and Mutlu Sezen3 ―fracture toughness of carbon/epoxy Laminates

[2] D.M.Hoyt, Stephen H. Ward and Pierre J.Minguet, ―Strength and fatigue life modeling of bonded joints in composite structure, Journal of Composites Technology and Research, 2002, p 1-32.

[3] T.Kant, and K.Swaminathan, ―Analytical solutions for the static analysis of laminated composite and sandwich plates based on higher order refined theory Composite Structures 56 (2002), p 329-344.

[4] Buket Okutan ―The effects of geometric parameters on the failure strength for pin- loaded multidirectional fiber-glass reinforced epoxy laminate, Composites Part B: engineering, 33 (2002) p 567–578.

[5] S.Y. Zhang, P.D. Soden and P.M. Soden ―Interlaminar shear fracture of chopped strand mat glass

[6] S.Y. Zhang, P.D. Soden and P.M. Soden "Interlaminar shear fracture of chopped strand mat glass fiber- reinforced polyester laminates", Journal of Composites Vol. 56, p 100-110, 1986.

[7] Mechanical testing of advanced fiber composite by J M Hodgkinson CRC Press

[8] Okenwa I. Okoli, Ainullotfi Abdul- Latif, ―Failure in composite laminates: overview of an attempt at prediction‖, Composites Part A: applied science and manufacturing, 33 (2002) p 315-321.

[9] Bhagwan D. Agarwal, Lawrence J. Broutman, ―Analysis and Performance of Fiber Composites‖, Second Edition, A Wiley-Interscience Publication.

[10] Leif A. Carlsson, R. Byron Pipes, ―Experimental Characterization of Advanced Composite Materials, Second Edition, Technomic Publishing Company.

[11] S.C. Sharma, ―Composite Materials , 2000, Narosa publishing house.

[12] Autar.K.Kaw, ―Mechanics of Composite Materials, CRC Press LLC.

[13] Kamal Sethi ―Investigation of damaged glass fiber reinforced polymer composites in 3-point bending

[14] K. Padmanabhan and Kishore "Influence of Circular Defects on the Flexural Strength of Kevlar/Epoxy composites